

SSC of MAXI experiment

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ABSTRACT

Monitor of All-sky X-ray Image (MAXI) on the International Space Station (ISS) has two kinds of X-ray detectors: the Gas Slit Camera (GSC) and the Solid-state Slit Camera (SSC). SSC is an X-ray CCD array, consisting of 16 chips, which has the best energy resolution as an X-ray all-sky monitor in the energy band of 0.5 to 10 keV. Each chip consists of 1024×1024 pixels with a pixel size of $24 \mu\text{m}$, thus the total area is $\sim 200 \text{ cm}^2$. We have developed an engineering model of SSC, i.e., CCD chips, electronics, the software and so on, and have constructed the calibration system. We here report the current status of the development and the calibration of SSC.

KEY WORDS: X-ray: detectors — detectors: CCD — SSC — International Space Station (ISS)

1. MAXI

Monitor of All-sky X-ray Image (MAXI: Matsuoka et al. 1997a, 1997b, 1999; Kawai et al. 1999; Mihara et al. 1999, 2000; Torii et al. 1999; Tomida et al. 2000a; Mihara et al. 2001b in this proceeding) is one of the first payloads of Japanese Experiment Module (JEM or KIBO)/Exposed Facility on the International Space Station (ISS). In one orbit of the ISS with 90 minutes, MAXI covers the whole sky. It is finally expected to monitor activities of about 2000–3000 X-ray sources with the limiting sensitivity of up to 1 mCrab (for detail, see Yuan et al. 2001 in this proceeding). The observation is scheduled to start in the beginning of 2005 and continue for two years.

MAXI consists of two kinds of X-ray detectors: the Gas Slit Camera (GSC: Mihara et al. 2001a, 2001b) and the Solid-state Slit Camera (SSC: Torii et al. 1999; Miyata et al. 1999, 2000; Tomida et al. 2000b; Kamazuka et al. 2001). The X-ray detector of the SSC is a CCD array, whereas that of the GSC is gas proportional counter. Hence, SSC has better energy resolution, and better detection efficiency in the soft energy band. We here report on the current status of the development of SSC.

2. SSC

2.1. Overview of SSC camera

MAXI has two SSC cameras (for the arrangement, see Mihara et al. 2001b in this proceeding), each of which is identical. Each SSC consists of an array of 16 CCD chips. The whole SSC is developed by NASDA and Osaka University. The principle of determining positions with a slit camera is found in Matsuoka et al. (1997a), Tomida et al. (2000a), and Mihara et al. (2001b) in this proceeding.

The schematic view of SSC is given in Fig. 2. SSC consists of three main parts: SSC Unit (SSCU), SSC Electronics (SSCE), and Data Processor (DP). The CCD chips and pre-amplifiers are contained in SSCU. The analogue signal generated in SSCU is digitized in SSCE, then, handled in DP, and sent to the telemetry as data packets (see section 2.3.).

2.2. CCD

The chips for SSC are developed by Hamamatsu Photonics K.K. and Osaka University. Table 1 lists the details of the CCD chip. The X-ray detection area is $25 \times 25 \text{ mm}^2$ for 1-chip, accordingly 200 cm^2 in total (for 2 SSCs). Since SSC is a slit camera, the CCD needs only one-

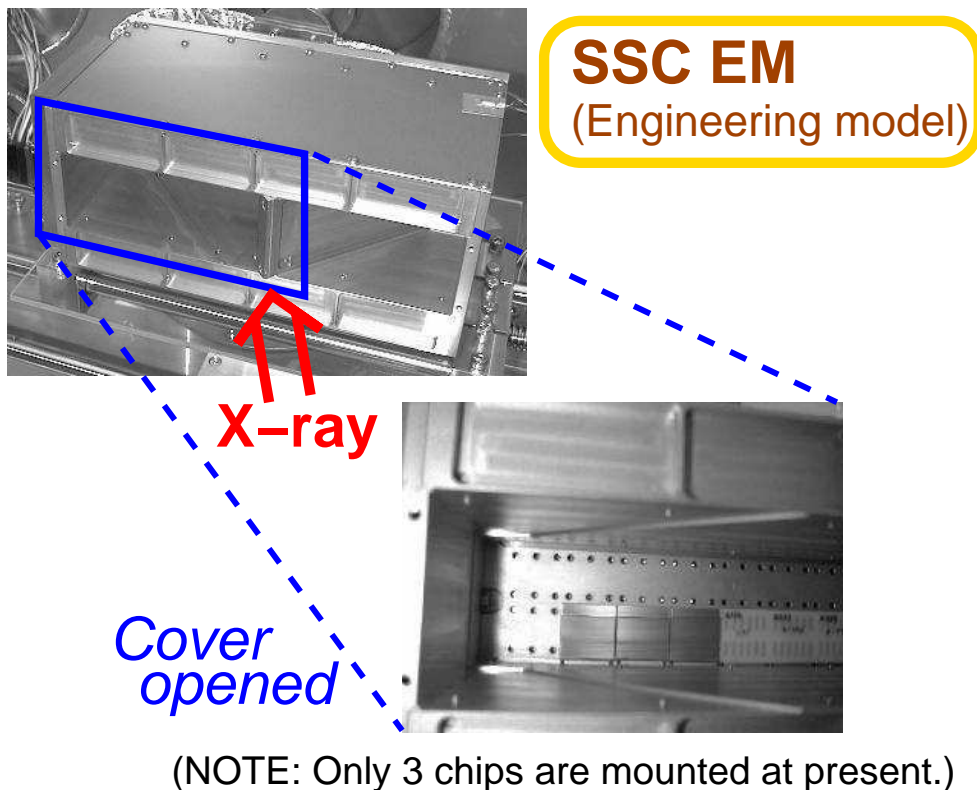


Fig. 1. The SSC EM where slat collimators are removed. Only 3 chips in 16 are currently mounted.

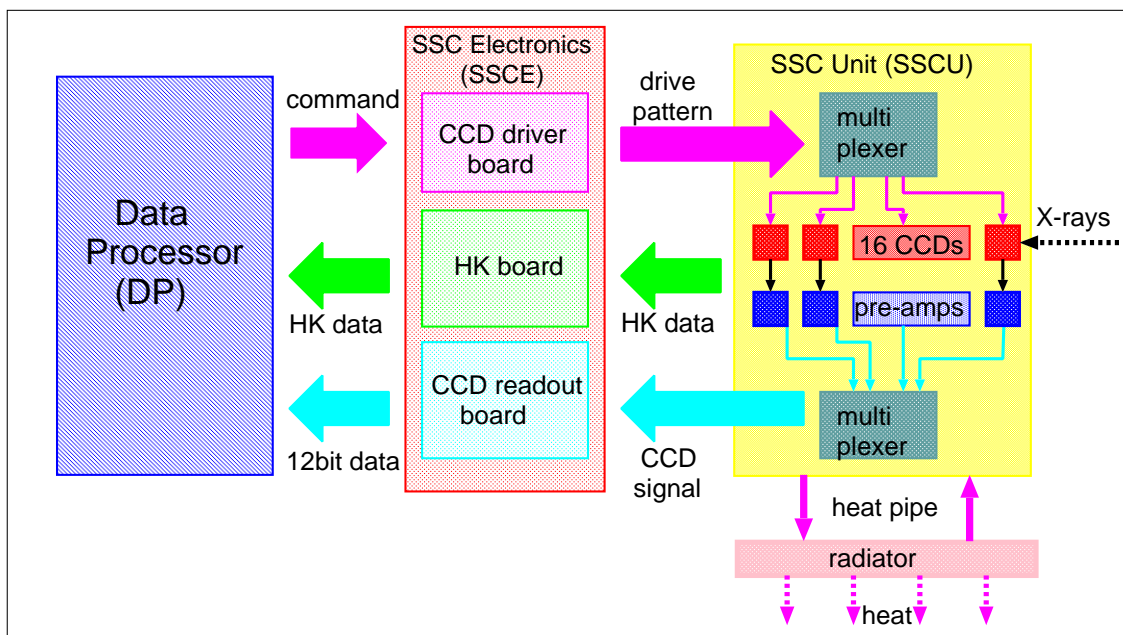


Fig. 2. Schematic view of SSC.

Table 1. details of MAXI-CCD chip

Parameters	Present	Goal	Unit
pixel size	24×24		μm
pixel number	1024×1024		
CTE	>99.999	>99.999	%
readout noise	6	< 4	e^- (RMS)
depletion layer	(\dagger)	>40	μm
energy resolution	150	130	eV^\ddagger
clocking pattern	2 phase, full frame transfer		
front/back-side	front-side illumination		
optical filter	by Al coating		
temperature	-60°C , using buried Peltier cooler		
readout method	Integration method		

\dagger : The thickness of depletion layer of the chips mounted on EM is less than $20\mu\text{m}$. However, we have already developed the chips with the depletion-layer thickness of $40\mu\text{m}$.

\ddagger : FWHM at 5.9 keV.

dimensional image; therefore, we adopt full-frame transfer type for the CCD chips of SSC. To block the optical light, aluminium (Al) is evaporated on the surface of the CCD chips. Whereas a large shock is generally expected in launch operation, this Al-coating method is tough for the shock, and accordingly makes it possible to design a simple structure for the whole camera. Note that this Al-coating also can minimize the radiative heat-input to the CCD chip.

X-ray CCDs must be cooled. To do this, we combine passive radiators, loop heat pipes (LHP) with liquid propylene fabricated by Swales K.K., and Peltier cooler buried in each CCD chip. The power consumed by Peltier cooler is $\sim 1 \text{ W/CCD}$, which can make the temperature difference on hot and cold sides in the Peltier cooler to be $\Delta T = 40^\circ\text{C}$. We expect that the hot side of the Peltier cooler can be cooled down to -20°C by LHP and the radiator, hence the CCD temperature of -60°C will be achieved. However, there may still remain some problems, which is being studied; e.g., the thermal environment around MAXI in the ISS is not completely fixed, or the condition in which the LHP works has not been well understood, yet. The detailed discussion is found in Tomida et al. (2000b).

The radiation damage is one of the most critical problems of the X-ray CCD observation in orbit, as seen in the case of *ASCA*/SIS (Yamashita et al. 1997) and *Chandra*/ACIS. Although the MAXI mission time of 2 years is not long, the accumulated radiation damage may cause significant degradation. We are looking for the most effective and practical method against this problem, such as the charge injection (CI) method (To-

mida et al. 1997). Detailed discussion is found in Tomida et al. (2001b).

2.3. Camera unit (SSCU), Electronics (SSCE), and Data Processor (DP)

SSCU and SSCE are fabricated by Meisei Electric K.K., and DP is, by NEC K.K. SSCE drives the SSCU and reads analogue signals from SSCU; since each SSCU has 16 CCDs, SSCE reads out the signals from those CCDs one after another by switching multiplexers in each SSCU. Then, SSCE digitizes the signal data into 12-bit data, and transfers them to DP.

We have tried three readout methods (for each pixel) in SSCE: integration, delay, and correlated double sampling (CDS). The respective methods are used in *Chandra*/ACIS and *ASTRO-E*/XIS (Hayashida et al. 1999), in *ASCA*/SIS (Burke et al. 1994), and in commercially available (optical) CCDs. We recorded the best performance with the integration method, hence adopted it.

The signal charges along the same columns in each chip are summed up like the fast mode in *ASCA*/SIS (Burke et al. 1994) or the P-sum mode of *ASTRO-E*/XIS (Hayashida et al. 1999) because only one-dimension positional information is required. In default, charges of 16 pixels are summed up, where we can indicate the number of bins by the command. The readout speed is 125 kHz; accordingly the readout time for all the 16 chips is ~ 9 sec in the default binning.

The algorithm of the data reduction in DP is also almost the same as that in the timing mode of *ASTRO-E*/XIS. The DP detects events, and sends the position, grade, and the summed pixel-level of each event to the telemetry. We have the frame- and dark-frame-modes for diagnosis, which are also the same as that of *ASTRO-E*/XIS.

2.4. Slit and Collimators

Fig. 3 shows the schematic view of the slit and the slat collimator system on SSCU to determine the photon arrival direction. The accuracy of estimated position mainly depends on the size of the slit; if the slit is narrower, the accuracy is better, but the effective area is smaller, and vice versa. The field of view of each SSC is $1 \sim 2^\circ \times 90^\circ$. The thickness of slat collimators will be $\sim 100\mu\text{m}$, which are aligned by $\sim 3\text{mm}$ pitch, although these values may be changed. Another point for the positional accuracy is flatness and non-reflectivity of the collimator. We are now searching for the best method to hold the flatness and to reduce surface reflectivity of the collimators. Mihara et al. (2001b) in this proceeding gives further information on this problem. We finally expect to determine the photon arrival direction with the accuracy of $\sim 1^\circ$ or better.

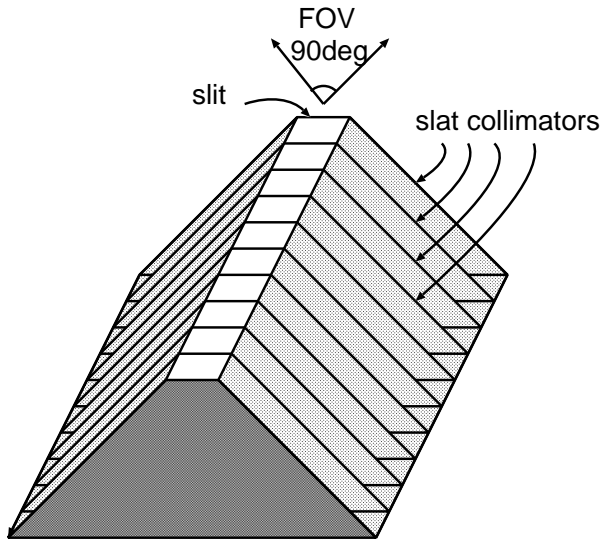


Fig. 3. Schematic view of the slit and the slat collimators of SSC.

3. Calibration

The calibration of CCD chips and the SSC-EM (Engineering model) is on-going at NASDA and Osaka University. For the flexible calibration system at Osaka University, which aims in particular at the calibration in the lower energy band below 2 keV, see Miyata et al. (2000) and Kamazuka et al. (2001). For the higher energy band above 1 keV, we use fluorescent X-rays from various metal elements (Torii et al. 1999; Tomida et al. 2000b), which is similar to the calibration system for the *ASTRO-E*/XIS at Kyoto University (Hamaguchi et al. 2000). Combining collimators and filters, illuminating fluorescent X-rays from each atom are purified according to the method in Hamaguchi et al. (2000). Fig. 4 shows the SSC-EM set in the vacuum chamber.

Fig. 5 shows the spectrum of ^{55}Fe K-lines with SSC-EM in the operation at -60°C , whereas Table 1 summarizes some important parameters obtained in the current calibration. We are steadily recording a FWHM of 150 eV or better for the energy resolution at 5.9 keV where single pixel events are accumulated, 6 electron (RMS) for the read-out noise, and more than 99.999% efficiency for the CTE (Charge Transfer Efficiency). Note that these values were obtained when we use preliminary chips and EM electronics; the improvement is on-going. We have already developed new chips with much thicker depletion layer of more than $40\mu\text{m}$, but have not combined it with the SSCE, yet. We have also made the preliminary version of the DP software; now it is being tested.

For the calibration of the collimator, which is important to determine the arrival direction of each X-ray photon, we will calibrate them using 19 m X-ray beam line at NASDA (see Torii et al. 1999). The absolute detection

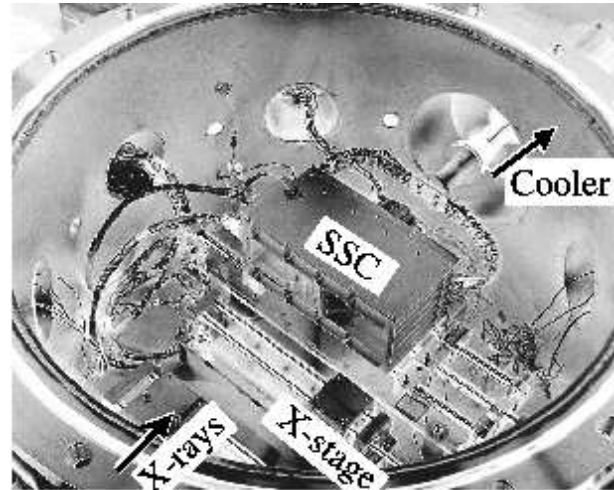


Fig. 4. SSC-EM is put in the center of the vacuum chamber. The back-side (upper-left) of SSC is a cold plate, which is cooled by mechanical cooler out of vacuum chamber. X-rays are illuminated from lower-left side, which is connected with another vacuum chamber where an X-ray generator is placed. In addition, a radio isotope ^{55}Fe can be set on the X-stage in front of SSC.

efficiency will be measured with well-calibrated reference detectors: X-ray proportional counters. We are now further improving all the SSCU including chips, SSCE, and DP, and will accomplish the SSC flight model (FM) until 2004.

4. Summary

We have been developing the CCD camera, SSC, which will be onboard the all-sky X-ray monitor MAXI on ISS/JEM. MAXI has two SSCs, and each SSC has 16 CCD chips fabricated by Hamamatsu Photonics K.K. At present, calibration and development of the engineering model of SSC are on-going. We achieved the energy resolution of 150 eV for the FWHM at 5.9 keV. Another chips with thicker depletion layer of more than $40\mu\text{m}$ have been developed. We are continuing the development, and plan to accomplish the flight model of SSC until 2004. The start of the MAXI observation is scheduled in the beginning of 2005.

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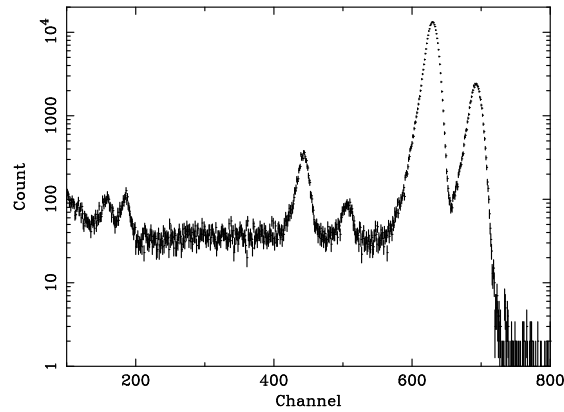


Fig. 5. SSC-EM spectrum of Mn K-lines (^{55}Fe). The FWHM of the main peak at 5.9 keV is 150 eV, where the statistical uncertainty is quite small, ~ 0.1 eV.

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